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Reflection enhances creativity: Beneficial effects of idea evaluation on idea generation

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ABSTRACT

The present study aimed to explore the neural correlates underlying the effects of idea evaluation on idea generation in creative thinking. Participants were required to generate original uses of conventional objects (alternative uses task) during EEG recording. A reflection task (mentally evaluating the generated ideas) or a distraction task (object characteristics task) was inserted into the course of idea generation. Behavioral results revealed that participants generated ideas with higher originality after evaluating the generated ideas than after performing the distraction task. The EEG results revealed that idea evaluation was accompanied with upper alpha (10–13 Hz) synchronization, most prominent at frontal cortical sites. Moreover, upper alpha activity in frontal cortices during idea generation was enhanced after idea evaluation. These findings indicate that idea evaluation may elicit a state of heightened internal attention or top-down activity that facilitates efficient retrieval and integration of internal memory representations.

1. Introduction

Creative products require both originality and effectiveness (Runco & Jaeger, 2012). This two-criterion statement has become a popular view since the 1960s. Creative responses are not only suggested to be original, but also appropriate (Jackson & Messick, 1965), relevant (Kneller, 1965), and worthwhile (Cropley, 1967). Nowadays, creativity is clearly defined as the ability to produce work that is novel (original, unique) and useful (Runco & Jaeger, 2012; Sternberg & Lubart, 1996). Based on such definitions, idea generation and idea evaluation constitute two fundamental processes of creative thinking (Runco, 2003; Sowden, Pringle, & Gabora, 2015). That is, generative processes are required to formulate original ideas, evaluative processes are required to select and/or refine those ideas into a form that is of value (Howard-Jones & Murray, 2003).

Generative and evaluative processes are emphasized in various models of creativity. The blind variation and selective retention (BVSR) theory of creativity (Campbell, 1960) is a two-step model in essence, which lays stress on the importance of totally random or "blind" variation, followed by selection of better ideas and their retention by the culture. The Darwinian theory of creativity (Simonton, 1999, 2007, 2010, 2013), which has its roots in the BVSR theory, includes a similar two-step process in which the production of ideas is followed by judgment of those ideas. The Geneplore model (Finke, Ward, & Smith, 1992) suggests that creative thinking consist of two stages, namely generation and exploration. Generation involves retrieval of items from memory, formation of associations between items, and synthesis and transformation of the "pre-inventive" structures. Exploration involves identifying the attributes of these pre-inventive structures and considering their potential function in different contexts.

It is suggested that idea generation and idea evaluation alternate during creative thinking process (Basadur, Graen, & Green, 1982; Kleinmintz, Goldstein, Mayseless, Abecasis, & Shamay-Tsoory, 2014; also see Sowden et al., 2015). This is also presented in artists' accounts of their own creative process. They often describe the process as alternating between rough sketching of ideas and critiquing ideas, which guide the next cycle of sketching and critiquing (cited in Ellamil, Dobson, Beeman, and Christoff (2012)). Conceivably, if idea evaluation exerts positive effects on idea generation, it helps the alternating cycle between idea evaluation and idea generation as well, which further supports creative

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processes. Whereas, previous studies revealed that if participants were instructed that they could evaluate their performance against some type of objective or social standard, they exhibited lower originality as compared to idea generation without such an instruction (Harkins & Szymanski, 1988; Silvia & Phillips, 2004; Szymanski & Harkins, 1987, 1992). This suggests that self-evaluation of one's own product against external standard may reduce creativity, perhaps because worrying about whether one's own performance will meet external standard reduces intrinsic motivation (Byron, Khazanchi, & Nazarian, 2010; Silvia & Phillips, 2004), which is critical for creative cognition (Amabile, 1996; Amabile & Pillemer, 2012; Hennessey, 2000). However, it is an open question whether and how an evaluation of self-generated ideas, without considering external standards, impacts on idea generation. Notably, this question is of theoretical significance to test the models which suggest that alternating of idea generation and idea evaluation contribute to the development of creative ideas (Basadur et al., 1982; Sowden et al., 2015).

The present study aimed to explore the effects of idea evaluation on idea generation during creative thinking. Specifically, we addressed two questions. First, does idea evaluation exert positive effects on idea generation? Second, how does idea evaluation modulate brain activity patterns that benefit idea generation? Since participants were asked to alternate between idea generation and idea evaluation for several times in the experiment, we preferred to use Electroencephalography (EEG) to explore the neural correlates underlying idea generation and idea evaluation because of its high temporal resolution.

Recent EEG studies have revealed that signals in several frequency bands, such as the theta (4–8 Hz), alpha (8–13 Hz), and beta (13–30 Hz) bands, are associated with creative thinking (Dietrich & Kanso, 2010). Particularly, EEG activity in the alpha band has been found to be highly sensitive to certain creativity-related factors (Fink & Benedek, 2014). First, the performance of creativity-demanding tasks induces stronger alpha event-related synchronization (ERS; i.e., task-related bandpower increases relative to baseline) than the performance of more "convergent" or intelligence-related tasks (Bazanova & Aftanas, 2008; Fink, Benedek, Grabner, Staudt, & Neubauer, 2007; Fink, Grabner, et al., 2009; Martindale & Hasenfus, 1978). Likewise, alpha ERS was found to be related to divergent rather than convergent modes of thinking within the same task (Jauk, Benedek, & Neubauer, 2012), as well as successful rather than unsuccessful insight problem solving (Cao, Li, Hitchman, Qiu, & Zhang, 2015). Second, more original ideas are accompanied by a stronger alpha activity at central–parietal (and to some minor extent also at anterior-frontal) sites (Fink & Neubauer, 2006; Grabner, Fink, & Neubauer, 2007). Third, alpha ERS correlates with an individual's creativity level (i.e., higher creative individuals showing stronger alpha power than lower creative ones when performing creativity tasks) (Fink, Grabner, et al., 2009; Fink, Graif, & Neubauer, 2009; Jausovec, 2000; Martindale, Hines, Mitchell, & Covello, 1984). Fourth, alpha ERS is sensitive to a verbal creativity training (Fink, Grabner, Benedek, & Neubauer, 2006) and to short-lasting creativity interventions (i.e., exposure to other people's ideas and induction of positive affect) (Fink, Schwab, & Papousek, 2011). Fifth, enhancing alpha power of the frontal cortex using 10 Hz transcranial alternating current stimulation (10 Hz-tACS) increases creativity, but 40 Hz-tACS unfolds no effects, which suggests that alpha activity in frontal brain areas is selectively involved in creativity (Lustenberger, Boyle, Foulser, Mellin, & Frohlich, 2015). Therefore, in this study, we analyzed EEG activity in the theta, alpha, and beta bands, but mainly focused on the activity in the alpha band.

Traditionally, alpha ERS has been considered to reflect cortical deactivation (Pfurtscheller & da Silva, 1999), whereas alpha event-related desynchronization (ERD; i.e., bandpower decreases) reflects cortical activation (Klimesch, 1999). However, alpha ERS has recently been demonstrated to reflect the absence of stimulus-driven, external bottom-up stimulation and, thus, a form of top-down activity (Payne & Sekuler, 2014; von Stein & Sarnthein, 2000) or a state of heightened internal attention (Benedek, Bergner, Koenen, Fink, & Neubauer, 2011; Benedek, Schickel, Jauk, Fink, & Neubauer, 2014; Fink & Woschnjak, 2011; Handel, Haarmeier, & Jensen, 2011; Jaarsveld et al., 2015; Jensen & Mazaheri, 2010; Klimesch, Sauseng, & Hanslmayr, 2007) that facilitates the (re-) combination of semantic information that is normally distantly related.

In the present study, participants were required to solve the Alternative Uses Task (AUT; Guilford, 1967) problems. The AUT is a typical creativity-related task. We administrated two kinds of interventions during the course of creative idea generation. One was to ask participants to *mentally evaluate the generated ideas* (reflection task). This task involves examination and intuitive evaluation of the creative output (Morewedge & Kahneman, 2010). The other was to ask participants to perform the *object characteristic task* (OC task), which required retrieving typical characteristics of conventional objects (such as "shoes" or "a coat hook"). The OC task is a relatively "convergent" task, involving the retrieval of prevalent, typical, or directly stimulus-related information (Binder, Desai, Graves, & Conant, 2009; Fink, Grabner, et al., 2009; Fink et al., 2010). In such a design, reflection required participants to evaluate the generated ideas, while performing the OC task distracted them from doing so. The EEG activity during solving the AUT problems was recorded in both conditions. Differences in behavioral performance and in EEG activity (in theta, alpha, and beta bands) changes from the pre- to the post-intervention period of idea generation were compared. We hypothesized that after a period of reflection, (1) participants would generate ideas with higher originality, and (2) changes in EEG activity related to the improvement of performance would be detected, probably most prominent in the alpha frequency band.

2. Methods

2.1. Participants

Twenty healthy right-handed college students (10 males, 10 females; range from 19 to 26 years of age, $M = 23.45$, $SD = 2.01$) of various academic disciplines participated individually in the study. They were all native Chinese speakers. They gave written informed consent prior to the EEG recording session, and received about 15 US dollars for their participation after the experiment. Due to technical problems, the data of four persons had to be excluded from the EEG analyses. The protocol of the experiment was approved by the Institutional Ethics Committee at East China Normal University.

2.2. Experimental task

The Alternative Uses Task (AUT) was used as the target task. It requires respondents to generate as many unusual and original uses for commonly used objects as possible, such as paperclip ("making a ring", "cleaning fingernails"). The AUT is a well-established creativity-demanding task, and performance on this task has been demonstrated to be a reliable predictor of creative potential (Runco & Acar, 2012). The AUT has been widely used in the studies on creativity (Kaufman, Plucker, & Baer, 2008; Runco, 1991, 1999; Runco & Mraz, 1992).

2.3. Experimental procedure

A within-subject design was used in this study. Each participant was presented with a total of 20 different AUT problems. He or she solved 10 problems (10 trials) in each of the two conditions (i.e., the reflection and distraction conditions). The 10 trials of one condition consisted of a block. The presented sequences of two blocks were balanced over all participants. The 20 AUT problems were randomly assigned to the two blocks for each participant. The participants were allowed to rest for 1 min between the two blocks.

The duration of a trial was 114 s (see Fig. 1). After a fixation of 20 s, the AUT item appeared on the screen. Similar to previous studies (Fink et al., 2011, 2012), participants were required to mentally generate ideas and then orally reported. Participants were told that "Please think about the unusual uses of the present object in 16 s, try your best to mentally produce the original ideas, and then orally report the most original idea in next 4 s." The period of the idea generation and subsequent response is referred to as Epoch 1. During the next 40 s, participants were asked to reflect on all ideas they just generated or work on an unrelated task.

In the reflection condition (see Fig. 1A), participants mentally evaluated the ideas they just generated in Epoch 1 for 30 s. They were instructed that "Your ideas will not be compared with any objective standard or other people's ideas. In next 30 s, you just think about how original the ideas you generated are." During the next 10 s, participants evaluated their cognitive engagement in reflection on a 5-point scale ranging from 1 (not at all) to 5 (very much). In the distraction condition (see Fig. 1B), participant were required to work on an unrelated task (i.e., OC task) to distract them from the target AUT problem. Specifically, one object (e.g., icebox, basketball) was presented on the screen, whose name was composed by two Chinese characters. Participants were instructed that "Please think about the typical characteristics of the object in 30 s, and then report the ideas in next 10 s." For the 10 trials in the distraction condition, ten objects were selected. These objects did not overlap with the conventional everyday objects used in the AUT.

After the intervention period (see Fig. 1), the participants resumed working on the same AUT problem and reported again only the most original idea (Epoch 2). They were instructed that "Please think about the unusual uses of the object once again in 16 s, and then report the most original idea that is different from the one you reported in epoch 1 during next 4 s." In both epochs, participants' oral responses for the AUT problems were recorded by a sound recorder and afterward transcribed for further analysis. The whole experiment took approximately 80 min for each participant.

2.4. EEG recording

Participants sat in a comfortable chair in a quiet, dim-lighted room that was sound-proof and electromagnetic-proof. They were faced with a CRT screen at eye level. Thirty channels of EEG signals and two channels of electrooculography (EOG) signals (horizontal and vertical eye movements) were recorded by a 32-channel BrainAmp amplifier (Brian Products GmbH, Munich, Germany). The impedance of the electrodes was generally kept below 5 kΩ during experiments. Thirty Ag–AgCl scalp EEG electrodes were arranged in the standard 10–20 system. EEG signals from each electrode were on-line referenced to FCz. The EEG and EOG signals were amplified, filtered (0.5–250 Hz band-pass), digitized (1000 Hz sampling rate), and stored for off-line analysis. An experimental trial started from the fixation onset to the end of Epoch 2. The EEG and EOG signals were recorded through each trial.

2.5. EEG preprocessing and ERD/ERS analysis

EOG-contaminated elements among the EEG signals were removed by an infomax independent component analysis (ICA) method implemented in EEGLAB toolbox (Swartz Center for Computational Neurosciences, US) (Delorme & Makeig, 2004). Signals in all 32 channels were down-sampled to 250 Hz and used for ICA. Independent components (ICs) representing eye movement artifacts were selected by both topography and temporal activities, and were removed from the EEG signals (Jung et al., 2000). Afterward, the EEG data were re-referenced using their common average reference, and then divided into epochs as Baseline, Activation-1, Activation-IN and Activation-2 (see Fig. 1). The mean value of each epoch was subtracted from that epoch for further analysis.

The EEG signals were first filtered by using an infinite impulse response (IIR) band-pass filter. Forward-and-reverse filtering was used to avoid phase distortions. Ripple amplitudes in the pass band and stop band were set as 0.0025 dB and 40 dB respectively. The filtered data were then squared to obtain the band power values. Brain activity during the tasks was then quantified as ERD/ERS values (Pfurtscheller & da Silva, 1999). In the theta (4–8 Hz), lower alpha (8–10 Hz), upper alpha (10–13 Hz), lower beta (13–20 Hz), upper beta (20–30 Hz) frequency bands, ERD/ERS values of the activation periods were calculated as following equation (Pfurtscheller & da Silva, 1999). $\mathrm{ERD/ERS} = (\mathrm{MP}_{\mathrm{activation}} - \mathrm{MP}_{\mathrm{baseline}})/\mathrm{MP}_{\mathrm{baseline}} \times 100$. In order to avoid overlap, the time periods for the spectrum calculation were selected from 2 s to 15 s during both Activation-1 and Activation-2, from 2 s to 29 s during the Activation-IN, and from 2 s till 19 s after the onset of Fixation during the Baseline.

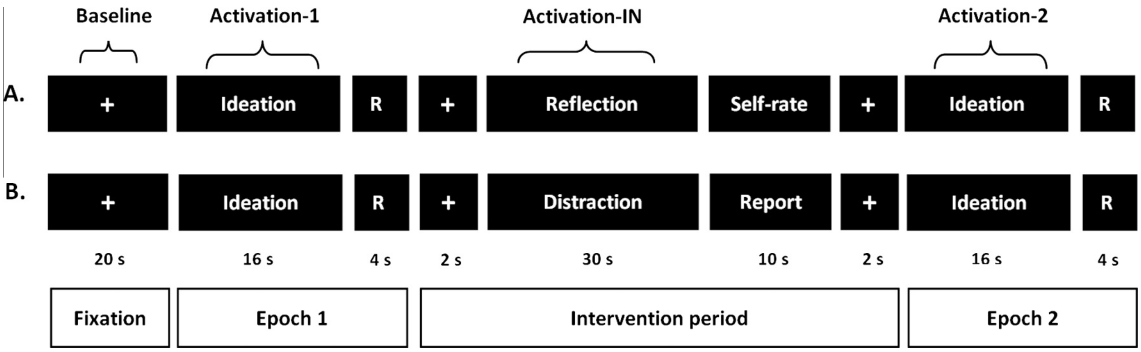

Fig. 1. (A) and (B) illustrate the experimental paradigms of the reflection and distraction conditions, respectively. + = the fixation; R = reported only the most original idea just generated.

2.6. Pre- and post-experimental tests

Since participants' anxiety states were found to influence the level of cortical arousal (Knyazev, Savostyanov, & Levin, 2005), their anxiety states were measured before the EEG recording by means of a Chinese version of the Spielberger's state-trait anxiety inventory (STAI; Li & Qian, 1995; Cronbach's alpha = .82 in the current study). Immediately after participants finished the experiment, they rated the level of mental effort in performing each of two interpolated tasks on a 9-point scale ranging from 1 (extremely low) to 9 (extremely high). Such a technique (i.e., *self-reported mental effort ratings*) is a widely used method to measure the level of cognitive demand of a task, which has been proven to be most sensitive to reflect the cognitive demand of intrinsic processing elicited by the task, relative to another two techniques for measuring cognitive demand (i.e., response time to a secondary task during task performance, and difficulty ratings of task) (Ayres, 2006; DeLeeuw & Mayer, 2008; Paas, Tuovinen, Tabbers, & Van Gerven, 2003).

2.7. Assessment of performance on AUT problems

The subjective scoring method was used to assess the performance on AUT problems, following the procedures outlined in previous studies (De Dreu, Nijstad, Baas, Wolsink, & Roskes, 2012; Gilhooly, Georgiou, Garrison, Reston, & Sirota, 2012; Hocevar, 1979; Silvia, 2011). (1) Five raters independently evaluated the originality for each idea reported by the participants on a 5-point Likert scale (1 – not original at all, 5 – highly original). The inter-rater agreement (ICCs = .71) was satisfactory. (2) The ratings for each single idea from the five raters were averaged into one originality score for each idea. Accordingly, each participant got 10 scores in Epoch 1 and in Epoch 2 for each condition. (3) The mean originality scores in Epoch 1 or Epoch 2 of each condition were calculated across problems for every participant. Finally, four mean originality scores (two conditions × two epochs) were available for every participant. These scores were used to explore the effects of condition and epoch on creative performance.

3. Results

3.1. Engagement and mental effort involved in reflection or distraction task

Participants' anxiety state scores ($M = 31.85$, $SD = 5.76$) were in acceptable levels, which did not significantly deviate from a normal range ($M = 45.31$, $SD = 11.99$) (Li & Qian, 1995). Participants' self-reports of engagement in reflection ($M = 3.75$, $SE = .19$) was significantly higher than the median score of 5-point scale (one-sample *t*-test, test value is 3), $t\ (15) = 3.87$, $p < .01$. This indicates that participants were truly involved in reflecting the generated ideas. As a check on whether participants actually engaged in performing the OC task during the intervention period, 20 other college students (10 females; age: $M = 22.56$, $SD = 2.07$) were recruited to work on the same OC task without EEG recording. Their performance on the OC task was used as comparison sample (see methods in Gilhooly et al., 2012; Hao et al., 2014). The results revealed that participants' performance ($M = 3.81$, $SD = 1.03$) did not differ significantly from that ($M = 3.96$, $SD = .95$) of the comparison sample, $t\ (34) = .45$, $p > .05$. This result indicated that the participants of current study engaged in the distraction task during the intervention period.

Participants' self-rated mental effort showed no difference between reflecting the generated ideas ($M = 2.44$, $SD = 1.63$) and performing the OC task ($M = 3.06$, $SD = 1.69$), $t\ (15) = 1.32$, $p > .05$. This result indicated that the reflection and distraction tasks had similar effortful demands for participants.

3.2. Originality of idea generation in the reflection and distraction conditions

The repeated measures ANOVA with epoch (EPOCH: Epoch 1 vs. Epoch 2) and condition (COND: reflection vs. distraction) as within-subject factors was performed on the mean originality scores. There were significant main effects of EPOCH, $F\ (1, 19) = 6.23$, $p < .05$, $\eta_p^2 = .25$, and COND, $F\ (1, 19) = 5.49$, $p < .05$, $\eta_p^2 = .22$. Overall, the originality scores were higher in Epoch 2 than in Epoch 1, and the scores were higher in the reflection than in the distraction condition. There was also a significant interaction effect of EPOCH × COND, $F\ (1, 19) = 5.08$, $p < .05$, $\eta_p^2 = .21$. Paired-sample t tests revealed that the originality scores under the reflection and distraction conditions in Epoch 1 ($M = 2.65$, $SD = .30$ vs. $M = 2.58$, $SD = .53$) were not significantly different from each other, $t\ (19) = .78$, $p > .05$. In Epoch 2, however, the originality scores between the two conditions ($M = 2.87$, $SD = .36$ vs. $M = 2.61$, $SD = .45$) displayed a significant difference, $t\ (19) = 3.55$, $p < .01$, Cohen's $d = .64$. Moreover, the scores in Epoch 2 were significantly higher than those in Epoch 1 under the reflection condition, $t\ (19) = 3.08$, $p < .01$, Cohen's $d = .66$, but was not under the distraction condition, $t\ (19) = .47$, $p > .05$ (see Fig. 2). These results indicated that idea evaluation unfolded beneficial effects on subsequent idea generation; viz. idea evaluation helped individuals generate ideas with higher originality.

3.3. EEG activity during activation-IN in two conditions

Five separate repeated measures ANOVAs with condition (COND: reflection vs. distraction), hemisphere (HEMI: left vs. right) and electrode position (POSI: $FP_{3,4}$, $F_{3,4}$, $F_{7,8}$, $FC_{1,2}$, $FC_{5,6}$, $C_{3,4}$, $P_{3,4}$, $P_{7,8}$, $T_{7,8}$, $O_{1,2}$) as within-subject factors were conducted for the ERD/ERS values of theta, lower alpha, upper alpha, lower beta, and upper beta frequency bands, respectively. The results are shown in Table 1.

For the theta, lower alpha, lower beta, upper beta bands, there were no main effects of COND, HEMI or POSI on the ERD/ERS values. Interaction effects were not significant, either.

However, for the upper alpha frequency band, the results revealed a significant main effect of COND, $F\ (1, 15) = 6.36$, $p < .05$, $\eta_p^2 = .30$, indicating stronger alpha activity in the reflection

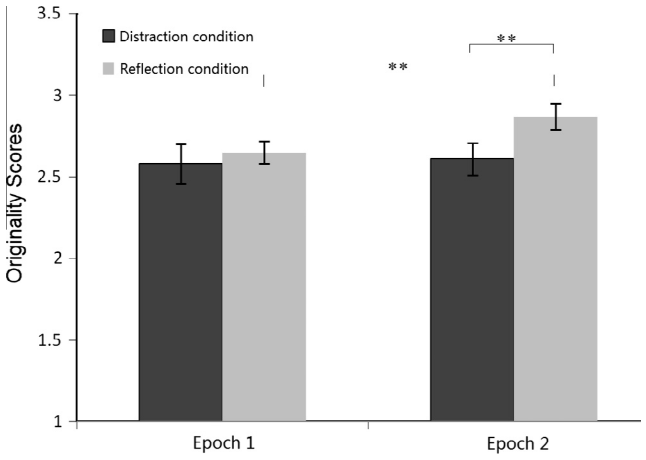

Fig. 2. Alternative uses task (AUT) originality scores in Epoch 1 and Epoch 2 separately under the reflection and distraction conditions. Error bars indicate standard errors of the mean. $^{**}p < 0.01$.

Table 1
The ANOVA results of ERD/ERS values in Activation-IN of theta (4–8 Hz), lower alpha (8–10 Hz), upper alpha (10–13 Hz), lower beta (13–20 Hz), and upper beta (20–30 Hz) bands.

	Theta	Lower alpha	Upper alpha	Lower beta	Upper beta
POSI	$F(3.03,45.4) = 2.79$	$F(3.18,47.63) = 1.06$	$F(3.12,46.72) = .25$	$F(1.51,22.66) = .81$	$F(1.07,16.09) = .81$
HEMI	$F(1,15) = .13$	$F(1,15) = 2.67$	$F(1,15) = .4$	$F(1,15) = .89$	$F(1,15) = .95$
COND	$F(1,15) = .1$	$F(1,15) = 2.39$	$F(1,15) = 6.36^{*}$	$F(1,15) = 3.32$	$F(1,15) = 1.53$
POSI ∗ HEMI	$F(2.59,38.83) = .7$	$F(3.85,57.79) = .28$	$F(2.88,43.24) = .57$	$F(2.32,34.77) = .94$	$F(2.09,31.3) = 1.48$
POSI ∗ COND	$F(2.26,33.83) = .88$	$F(2.41,36.11) = .46$	$F(4.21,63.08) = 2.78^{**}$	$F(1.26,18.86) = .99$	$F(1.09,16.3) = .5$
HEMI ∗ COND	$F(1,15) = 1.62$	$F(1,15) = 2.42$	$F(1,15) = .01$	$F(1,15) = .24$	$F(1,15) = .08$
POSI ∗ HEMI ∗ COND	$F(3.11,46.6) = .58$	$F(4.49,47.42) = .47$	$F(4.8,72.06) = 1.87$	$F(2.05,30.82) = .33$	$F(2.06,30.87) = .96$

[*] $p < 0.05$.
[**] $p < 0.01$.

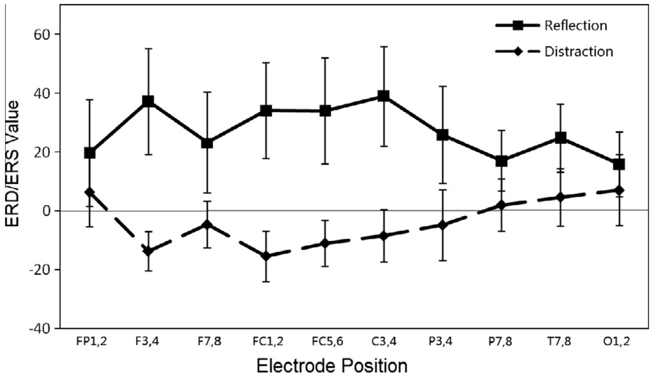

Fig. 3. ERD/ERS values in the upper alpha band (10–13 Hz) of the reflection and distraction performance. Error bars indicate standard errors of the mean.

than in the distraction performance. Also, the ANOVA results (Greenhouse–Geisser corrected *df*s) showed a significant interaction effect of COND × POSI, F (4.21, 63.08) = 2.78, $p < .05$, $\eta_p^2 = .16$. Specifically, frontal ($F_{3,4}$, $FC_{1,2}$, $FC_{5,6}$) and central ($C_{3,4}$) sites showed stronger alpha activity during reflection than during the distraction condition (post hoc Tukey HSD test, $ps < .05$), while there was no difference in other positions (see Figs. 3 and 4).

3.4. EEG activity during Activation-1 and Activation-2 in two conditions

Five separate ANOVAs for repeated measures with COND, HEMI, POSI and EPOCH (Activation-1 vs. Activation-2) as within-subject factors were conducted on the ERD/ERS values of theta, lower alpha, upper alpha, lower beta, and upper beta frequency bands, respectively. The results are shown in Table 2.

For the theta band, there was a significant interaction effect of POSI × HEMI × EPOCH, $F(4.04, 60.58) = 3.25$, $p < .05$, $\eta_p^2 = .18$. During Activation-1, theta activity in the left hemisphere showed stronger in the electrode position (F_3) than in other three positions (FC_1, T_3, and P_7) (post hoc Tukey HSD test, $ps < .05$), but such differences were not observed in the left hemisphere during Activation-2. Furthermore, there was neither main effect of COND, nor interaction effect of COND and any of other three variables.

For the upper alpha band, there was no main effect of COND, HEMI, POSI or EPOCH. However, interaction effects of POSI × EPOCH (F (4.12, 61.85) = 2.62, $p < .05$, $\eta_p^2 = .15$) and POSI × COND × EPOCH (F (3.81, 59.71) = 2.86, $p < .05$, $\eta_p^2 = .16$) were significant. Specifically, the frontal areas ($FC_{1,2}$ and $FC_{5,6}$) showed stronger alpha activity during Activaiton-2 in the reflection than in the distraction condition (post hoc Tukey HSD test, $ps < .05$), while there was no difference of alpha activity during Activation-1 between these two conditions (see Fig. 4).

4. Discussion

Previous studies suggested that alternating between idea generation and idea evaluation contribute to creative ideas to develop. However, no empirical study investigated whether idea evaluation would benefit idea generation, as well as the underlying neural correlates. The present study required participants to solve a traditional divergent thinking problem (i.e., the AUT), with a reflection task or a distracting task (i.e., the OC task) inserted into the course of idea generation. The behavioral results revealed that the originality of the generated ideas after the interpolated reflection task improved much more than that after the distracting task.

The EEG results revealed that our interventions on creative idea generation were reflected prominently in the upper alpha frequency band, in line with a large number of previous studies (Benedek et al., 2011; Fink, Grabner, et al., 2009; Fink et al., 2011; Jaarsveld et al., 2015; Jauk et al., 2012; Schwab, Benedek, Papousek, Weiss, & Fink, 2014). As compared with performing the OC task, reflecting on the generated ideas was accompanied with stronger increases in the alpha activity relative to a pre-stimulus baseline period, most prominent at frontal sites (see Figs. 3 and 4). It has been shown that frontal alpha synchronization appears to reflect high internal processing demands or a state of enhanced internally oriented attention (Benedek et al., 2011, 2014; Cooper, Burgess, Croft, & Gruzelier, 2006; Cooper, Croft, Dominey, Burgess, & Gruzelier, 2003; Fink, Grabner, et al., 2009; Jaarsveld et al., 2015; Klimesch et al., 2007). The observed alpha synchronization in evaluating the generated ideas could plausibly reflect the absence of stimulus-driven, external bottom-up stimulation and, thus, a form of top-down activity or a state of heightened internal attention that facilitates free floating association in semantic networks (von Stein & Sarnthein, 2000), thereby positively influencing generation of creative ideas. This explanation was in line with the findings of a recent fMRI study (Ellamil et al., 2012), which showed that creative idea evaluation was associated with joint recruitment of executive and default network regions, and these two networks showed positive functional connectivity throughout task performance.

In contrast, performing the OC task was generally associated with decreased alpha activity relative to the pre-stimulus reference period at frontal sites (see Figs. 3 and 4). The OC task, which requires the retrieval of prevalent, typical, or directly stimulus-related information, may involve more stimulus-driven demands, placing lower demands on top-down information processing. Interestingly, there was no beneficial effect of such kind of information processing on later idea generation.

Neural correlates of idea generation in the post-intervention period were influenced by the interpolated tasks. Specifically, after a period of reflection, subsequent idea generation (i.e., Activation-2) was generally accompanied with increasing alpha activity relative to the pre-intervention period (i.e., Activation-1) at frontal sites ($FC_{1,2}$ and $FC_{5,6}$) (see Fig. 4). This finding indicates that idea evaluation might enhance internal attentional state or top-down

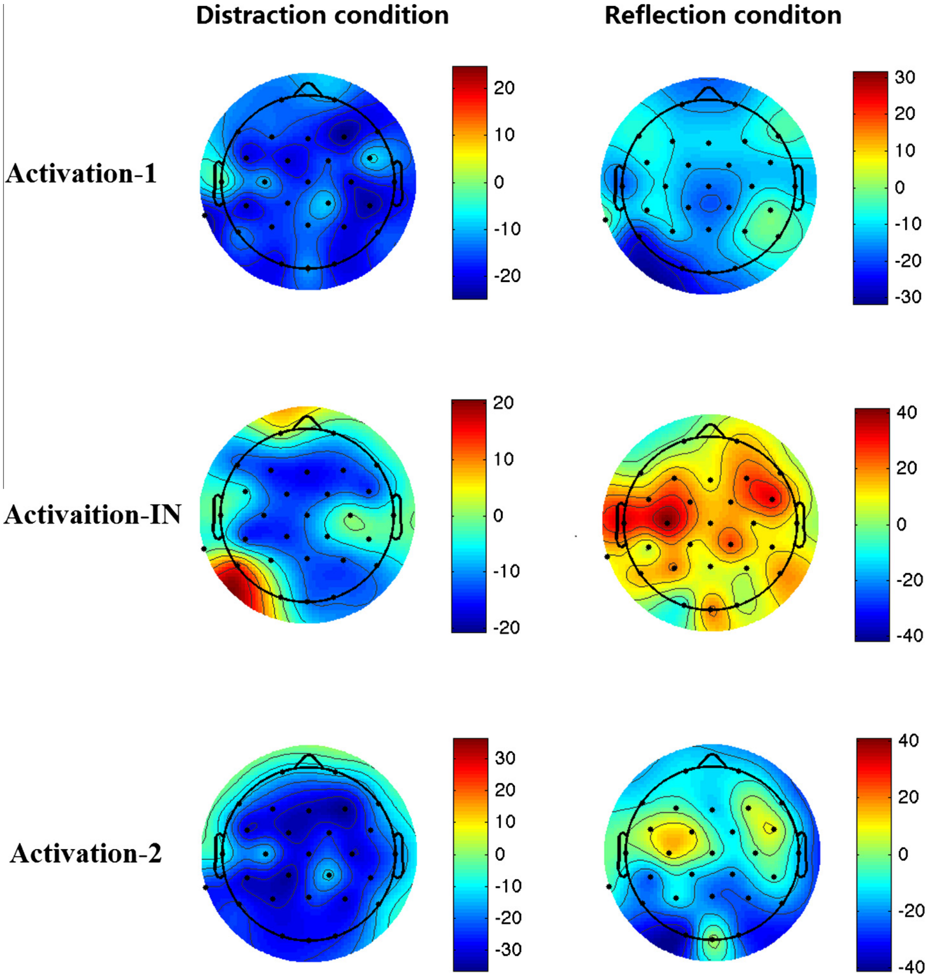

Fig. 4. The topographies of ERD/ERS values in the alpha band (10–13 Hz) during Activation-1, Activation-IN and Activation-2 in the reflection and distraction conditions.

Table 2
The ANOVA results of ERD/ERS values in Activation-1 and Activation-2 of theta (4–8 Hz), lower alpha (8–10 Hz), upper alpha (10–13 Hz), lower beta (13–20 Hz), and upper beta (20–30 Hz) bands.

	Theta	Lower alpha	Upper alpha	Lower beta	Upper beta
POSI	$F(2.76,41.39) = 2.17$	$F(3.04,45.66) = 1.24$	$F(2.88,43.28) = 1.02$	$F(3.69,55.36) = .25$	$F(3.52,52.81) = .33$
HEMI	$F(1,15) = .48$	$F(1,15) = 1.98$	$F(1,15) = .02$	$F(1,15) = .36$	$F(1,15) = .4$
COND	$F(1,15) = .05$	$F(1,15) = 3.61$	$F(1,15) = 1.22$	$F(1,15) = .25$	$F(1,15) = 3.52$
EPOCH	$F(1,15) = .13$	$F(1,15) = .05$	$F(1,15) = .01$	$F(1,15) = .75$	$F(1,15) = .54$
POSI ∗ HEMI	$F(4.31,61.68) = 1.73$	$F(3.53,53.02) = .62$	$F(3.96,59.43) = .48$	$F(2.95,44.21) = 1.27$	$F(3.6,53.94) = 1.53$
POSI ∗ COND	$F(3.34,50.14) = .87$	$F(3.76,56.4) = .48$	$F(3.45,51.67) = 1.74$	$F(4,60.06) = .38$	$F(2.45,36.67) = 2.59$
POSI ∗ EPOCH	$F(3.89,58.31) = 1.12$	$F(2.48,37.15) = .64$	$F(4.12,61.85) = 2.62^{*}$	$F(3.33,35.01) = .67$	$F(1.43,21.43) = .39$
HEMI ∗ COND	$F(1,15) = 3.36$	$F(1,15) = 2.97$	$F(1,15) = 1.15$	$F(1,15) = .3$	$F(1,15) = .6$
HEMI ∗ EPOCH	$F(1,15) = .28$	$F(1,15) = .31$	$F(1,15) = 1.27$	$F(1,15) = .22$	$F(1,15) = 2.03$
POSI ∗ HEMI ∗ COND	$F(4.34,65.09) = 1.05$	$F(4.04,60.61) = .42$	$F(4.22,63.32) = .53$	$F(4.5,67.49) = .74$	$F(3.73,55.92) = 1.12$
POSI ∗ HEMI ∗ EPOCH	$F(4.04,60.58) = 3.25^{*}$	$F(3.64,54.57) = .97$	$F(3.75,56.19) = .38$	$F(3.69,55.4) = .88$	$F(2.39,35.78) = .77$
POSI ∗ COND ∗ EPOCH	$F(3.8,56.98) = 1.09$	$F(3.77,56.48) = 1.14$	$F(3.81,57.08) = 2.86^{*}$	$F(4.34,65.04) = 1.41$	$F(1.49,22.38) = .33$
HEMI ∗ COND ∗ EPOCH	$F(1,15) = .2$	$F(1,15) = 2.27$	$F(1,15) = 2.09$	$F(1,15) = 3.13$	$F(1,15) = 3.79$
POSI ∗ HEMI ∗ COND ∗ EPOCH	$F(2.61,39.16) = .47$	$F(3.84,57.52) = .47$	$F(3.98,59.71) = .87$	$F(2.98,44.73) = .92$	$F(2.1,31.48) = .54$

[*] $p < 0.05$.

activity in subsequent idea generation, which might inhibit the retrieval of typical information, and allow more remote or original responses come into conscious awareness (Fink et al., 2007, 2011; Fink, Grabner, et al., 2009; Fink, Graif, et al., 2009). In the distraction condition, however, there was no such difference of alpha activity between in Activation-1 and in Activation-2 (see Fig. 4).

It should be noted that participants' self-reports of engagement in reflection and their performance on the OC task indicated that they were involved in performing these two intervention tasks. It was likely that participants did not consciously work on the AUT problems during the intervention periods. Also, the self-rated mental efforts were not different between these two intervention tasks. Thus, the positive effects of reflection (i.e., idea evaluation) on later idea generation cannot be contributed to the effects of mental effort that reflection elicited.

Taken together, the results of this study demonstrated that idea evaluation was associated with increasing alpha activity at frontal sites, as well as enhanced frontal alpha activity during later idea generation. Given the close relationship between alpha activity and internal attentional state or top-down activity, our findings suggested that idea evaluation might elicit a state of internal attention or top-down activity that facilitates efficient retrieval and integration of internal memory representations.

There are two limitations of this study. First, the present results are true for creative ideation tasks in the verbal domain to use conceptual stimuli, but it remains uncertain for figural ideation tasks that require stronger sensory processing of the visual-spatial stimulus properties (Jausovec & Jausovec, 2000). Therefore, future study about the effects of idea evaluation on idea generation when participants solve the figural ideation problems will be interesting. Second, based on the current results, we could not explain why the reflection and distraction performance resulted in different neural patterns in subsequent idea generation. The top-down or bottom-up hypotheses should be tested with more delicate experimental design.

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